5.5 INCINERATORS

This section presents the basic operating principles, typical designs, industrial application, and costs of incinerators used as control devices. An incinerator is the only PM control device that does not concentrate the PM for subsequent disposal. An incinerator utilizes the principles of combustion to control pollutants. Incinerators used as add-on control devices are however, seldom used to remove only particulate matter (PM); PM control is usually desirable as a secondary treatment of a gas stream with a high volatile organic compounds (VOC) content.[1] The type of PM that is usually controlled by an incinerator is commonly composed of soot (particles formed as a result of incomplete combustion of hydrocarbons (HCs)), coke, or carbon residue. There are two basic types of incinerators used as add-on control devices: thermal and catalytic. For purposes of PM control, the use of a catalytic incinerator is limited because catalysts are subject to blinding from the PM.[2]

There are several advantages to using incinerators for waste air streams that contain VOC and PM. These advantages are: simplicity of operation; capability of steam generation or heat recovery in other forms; and capability for virtually complete destruction of organic contaminants. Disadvantages include: relatively high operating costs (particularly associated with fuel requirements); potential for flashback and subsequent explosion hazard; and incomplete combustion possibly creating potentially worse pollution problems.[3] High gas velocities are usually required for incinerators used for PM control to prevent settling of PM.[5] This may increase the incinerator size necessary to achieve the minimum required gas residence time.

5.5.1 Incinerator Control Mechanisms

Incinerator control is based on the principle that at a sufficiently high temperature and adequate residence time, any HC can be oxidized to carbon dioxide (CO_2) and water. In an incinerator, PM containing HCs is first vaporized to a gas and then oxidized.[1]

To achieve complete combustion, i.e. convert all the HC to CO_2 and water, sufficient space, time, turbulence and temperature high enough to ignite the constituents must be provided by the incinerator. The "three T's" of combustion: time, temperature, and turbulence, govern the speed and completeness of the combustion reaction. For complete combustion, oxygen must come into close contact with the combustible molecule at sufficient temperature and for a sufficient length of time for the reaction to be complete.[2]

The combustion time required for PM control is dependent on particle size and composition, oxygen content of the furnace, atmosphere, furnace temperature, gas velocity, and extent of mixing of the combustibles. For PM less than 100 µm in diameter, the combustion rate is controlled by chemical kinetics; for PM greater than 100 µm, diffusion controls the combustion rate.[1] In collection devices (ESP's, fabric filters, scrubbers) diffusion controls the collection rate of particles less than 1 µm in diameter.

For particles smaller than 100 µm the time required for complete combustion can be calculated using the following equation:[1]

$$t_c = (D\ d_p)/(2\ K_s\ p_g) \qquad \text{Eq. 5.5-1}$$

where for coke and carbon residue,

$$K_s = 8{,}710\ \exp(-35{,}700/RT_s) \qquad \text{Eq. 5.5-2}$$

and for soot,

$$K_s = (1.085 \times 10^4\ T_s^{-½})\ (\exp(-39{,}300/RT_s) \qquad \text{Eq. 5.5-3}$$

where t_c is the combustion time for a chemical kinetics controlled reaction (sec), D is the density of particle (g/cm^3), d_p is the diameter of particle (cm), K_s is the surface reaction rate coefficient (g/cm^2-sec-atm), p_g is the partial pressure of oxygen in combustion air (atm), R is the universal gas law constant (82.06 atm-cm^3/mole-°K), T_s is the surface temperature of the particle (assumed to be the incinerator temperature) (°K).

With the proper residence time, complete combustion should result in >99 percent control of particles containing HCs. Figure 5.5-1 shows the theoretical residence time needed for >99 percent control of various sized coke PM in an incinerator operated from 1200-2000°F calculated using the above equations.[1]

Although residence time and incinerator temperature are the primary incinerator parameters affecting incinerator performance, other important parameters are the heat content and water content of the gas stream, and the amount of excess combustion air (i.e. amount above the stoichiometric amount needed for combustion). Combustion of gas streams with heat contents less than 50 Btu per standard cubic foot of air (SCF) usually will require supplemental fuel to maintain the desired combustion temperature. Supplemental fuel may also be needed for flame stability, regardless of the heat content of the gas.[4]

For incinerators operated above 1400°F, the oxidation reaction rates become much faster than the gas diffusion mixing rate. As a result, the combustion reaction may be hindered because sufficient

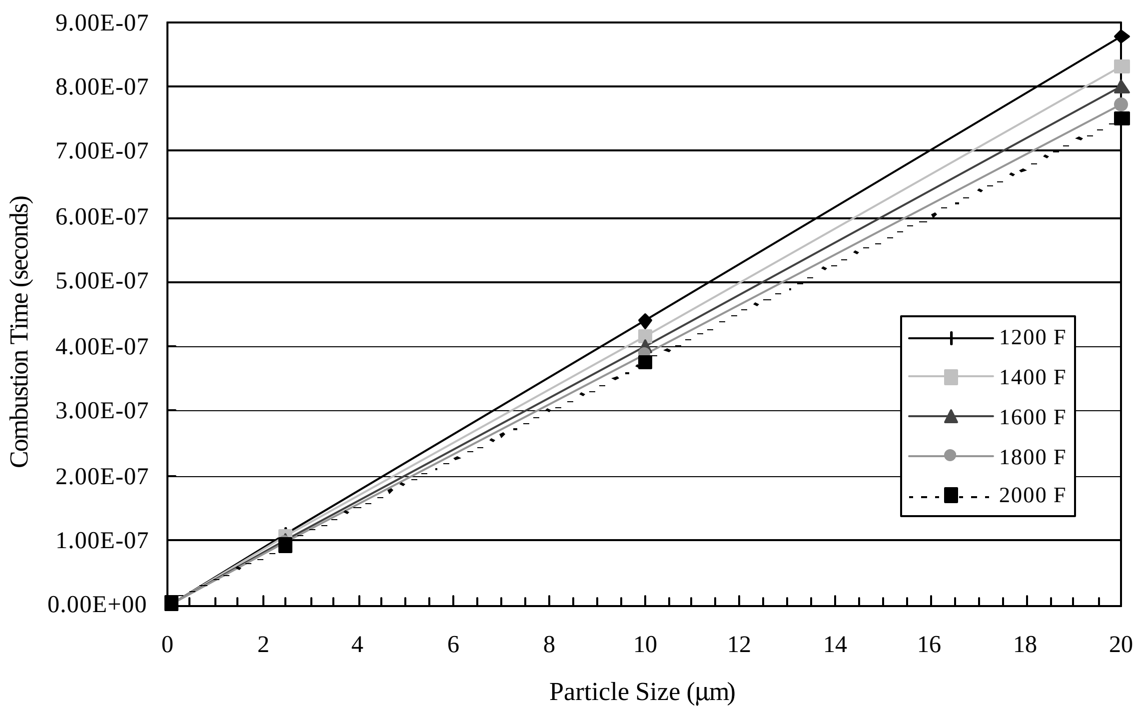

Figure 5.5-1. Calculated Theoretical Residence Times for Various-sized Coke PM in an Incinerator at Various Temperatures

oxygen molecules are not in proximity to the HCs. To ensure that this does not occur, mixing must be enhanced via vanes or other physical methods.[5]

5.5.2 Types of Incinerators

As discussed above, there are two basic types of incinerators, thermal and catalytic. Both types of incinerator may use heat exchangers to recover some of the heat energy from the incinerator. Therefore, this section discusses both types of incinerators as well as heat exchangers.

5.5.2.1 Thermal Incinerators

A typical thermal incinerator is a refractory-lined chamber containing a burner (or set of burners) at one end. Thermal incinerators typically use natural gas to supplement the caloric content of the waste gas stream. In a thermal incinerator, the combustible waste gases pass over or around a burner flame into a residence chamber where oxidation of the waste gases is then completed. The most recent guidelines for incinerators to promote more complete destruction of VOC are:[5]

- A chamber temperature high enough to enable the oxidation reaction to proceed rapidly to completion (1200-2000 °F or greater);

- Flow velocities of 20-40 feet per second, to promote turbulent mixing between the hot combustion products from the burner, combustion air, and waste stream components; and

- Sufficient residence time (approximately 0.75 seconds or more) at the chosen temperature for the oxidation reaction to reach completion.

The following sections discuss the two types of thermal incinerators: discrete burner and distributed burner. Both types may also use heat recovery equipment. This equipment is discussed in Section 5.5.2.3 below.

5.5.2.1.1 Discrete Burner Thermal Incinerator. In a discrete dual burner incinerator, shown in Figure 5.5-2, the waste gas stream and combustion air feed into a

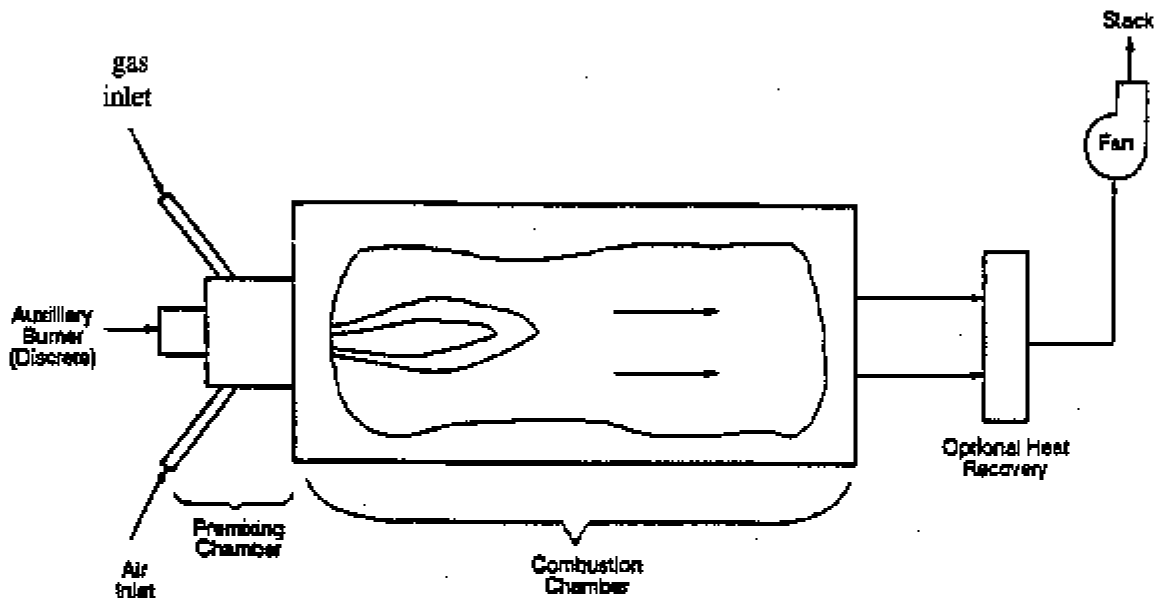

Figure 5.5-2. Schematic Diagram of a Discrete Burner Thermal Incinerator (Reference 4).

premixing chamber fitted with a (auxiliary) discrete fuel burner. In this chamber, both gases are thoroughly mixed and pre-heated by the auxiliary burner. The mixture of hot reacting gases then passes into the main combustion chamber where another (primary) burner is located. This chamber is sized to allow the mixture enough time at the elevated temperature for the oxidation reaction to reach completion. Energy can the be recovered from the hot flue gases in a heat recovery section.[6]

5.5.2.1.2 Distributed Burner Thermal Incinerator. Thermal incinerators (that use natural gas as the supplemental fuel) may also use a grid-type, or distributed, gas burner. This gas burner configuration is shown in Figure 5.5-3. In a distributed thermal incinerator, small gas flame jets on a grid surface ignite the vapors in the gas as it passes through the grid. The grid acts as a baffle to promote mixing before the gases enters the second part of the incinerator chamber. Because there are many small flames distributed on the entire cross-section of the combustion chamber and the vapors are well-mixed, this arrangement enables the gas vapors to burn at a lower chamber temperature and allows for the use of less fuel than the discrete burner configuration, described above.[4] In the discrete burner, vapors and particles are more likely to survive the single large flame initially, so the chamber must be maintained at a higher temperature to ensure complete combustion.

5.5.2.2 Catalytic Incinerators

A catalytic incinerator is not usually recommended as a control device for PM since the PM, unless removed prior to incineration, will often coat the catalyst so that the catalyst active sites are prevented from aiding in the oxidation of pollutants in the gas stream. This effect of PM on the catalyst is called blinding.[2] Despite this drawback, catalytic incinerators are sometimes used for PM control in the chemical manufacturing and textile industries, and for combustion sources such as IC engines, boilers, and dryers.[7] Therefore, a brief description of this type of incinerator is included here.

Catalytic incinerators are very similar to thermal oxidation, with the primary difference that the gas, after passing through the flame area, passes through a catalyst bed.[5] The catalyst has the effect of increasing the oxidation reaction rate, enabling conversion at lower reaction temperatures than in thermal incinerator units. Catalysts, therefore, also reduce the incinerator volume/size.[5] Catalysts typically used for VOC incineration include platinum and palladium. Other formulations include metal oxides, which are used for gas streams containing chlorinated compounds.[4]

A schematic of a catalytic incinerator is presented in Figure 5.5-4.[4] in a catalytic incinerator, the gas stream is introduced into a mixing chamber where it is also heated. The waste gas usually passes through a recuperative heat exchanger (discussed below), where it is preheated by post-combustion gas.[11] The heated gas then passes through the catalyst bed. Oxygen and VOCs migrate to the catalyst surface by gas diffusion and are adsorbed onto the catalyst active sites on the surface of the catalyst where oxidation then occurs. The oxidation reaction products are then desorbed from the active sites by the gas and transferred by diffusion back into the gas stream.[8]

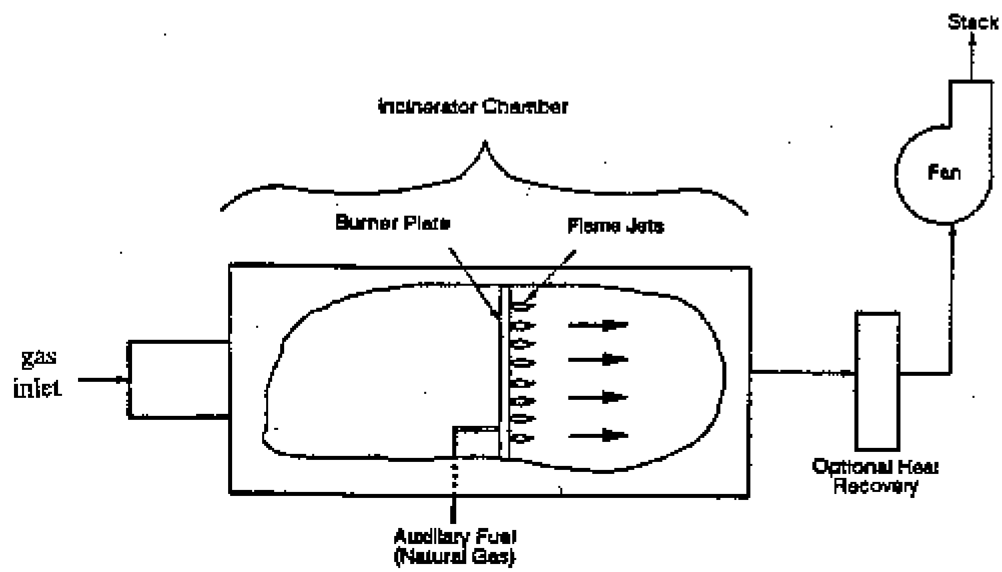

Figure 5.5-3. Schematic Diagram of a Distributed Burner Thermal Incinerator (Reference 6).

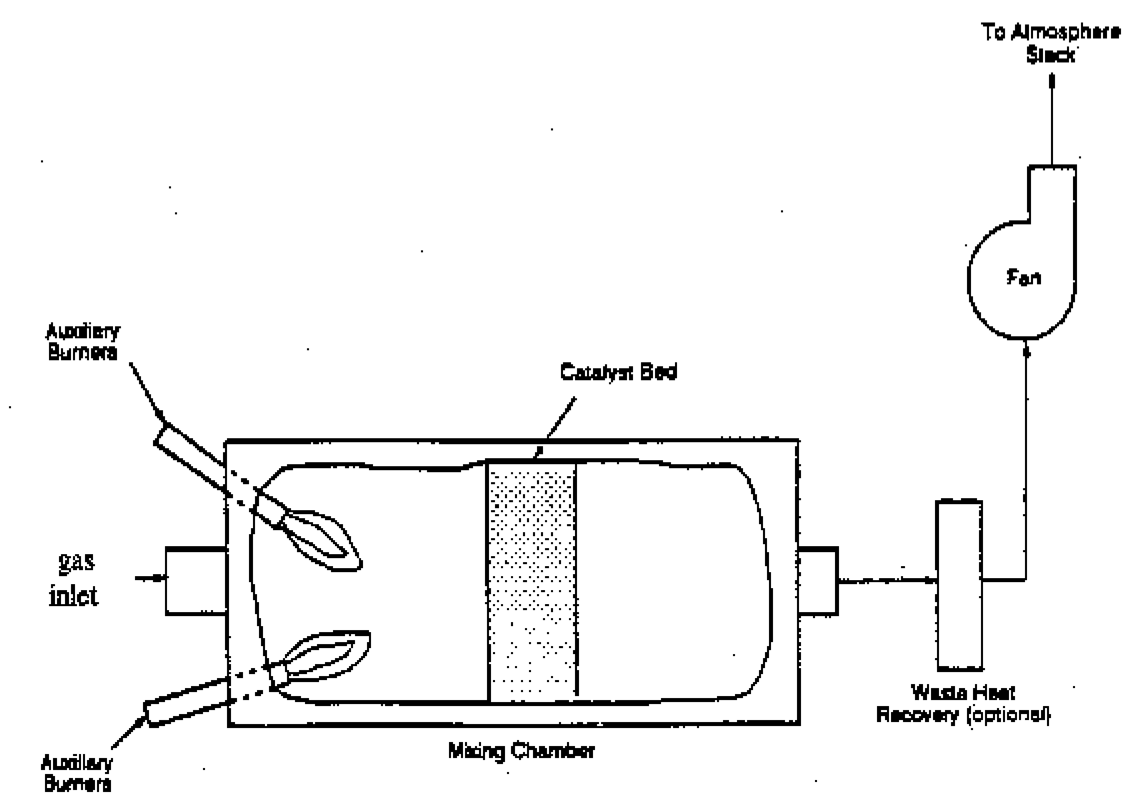

Figure 5.5-4. Schematic Diagram of a Catalytic Incinerator (Reference 4).

As discussed above, PM can rapidly blind the pores of the catalysts and deactivate the catalyst over time. Because essentially all the active surface of the catalyst is contained in relatively small pores, the PM need not be large to blind the catalyst. No general guidelines exist as to the PM concentration and size that can be tolerated by catalysts because the pore size and volume of catalysts vary greatly.[9] This information is likely to be available from the catalyst manufacturers.

The advantages of catalytic combustion reactors over thermal incinerators, therefore, include:[5]

- Lower fuel requirements,
- Lower operating temperatures,
- Little or no insulation requirements,
- Reduced fire hazards, and
- Reduced flashback problems.

The disadvantages include:[5]

- Higher capital costs,
- Catalyst blinding causes operational problems and/or higher maintenance requirements (annual costs),
- PM may need to be precollected, and
- Spent catalyst that cannot be regenerated may need to be disposed.

5.5.2.3 Heat Recovery Equipment

Since the flue gas that is still hot after exiting the incinerator, heat may be recovered with the proper auxiliary incinerator equipment. Heat recovery equipment for an incinerator can be either recuperative or regenerative. Recuperative heat exchangers, that recover heat on a continuous basis, include crosscurrent-, countercurrent-, and cocurrent-flow heat exchangers. For a given heat flow and temperature drop, recuperative heat exchanger surface requirements will be the lowest in a countercurrent flow configuration.

Regenerative heat exchangers recover heat by intermittent heat exchange through alternate heating and cooling of a solid. Heat flows alternately into and out of the same exchanger as air and flue gas flows are periodically reversed. The heat sink and heat transfer area for regenerative heat exchangers can be either a fixed bed, a moving bed or a rotary cylinder.[1]

5.5.3 Control Efficiency

5.5.3.1 Control Efficiency for Volatile Organic Compounds

Theoretically, all organic material, including VOC, are combustible with combustion efficiency limited only by cost. On the basis of studies of thermal incinerator efficiency, it has been concluded that at least 98 percent VOC destruction (or a 20 part per million by volume (ppmv) VOC exit concentration) is achievable by all well-designed incinerators. An estimate of 98 percent efficiency is predicted for thermal incinerators operating at 1,400°F or higher, with at least 0.75 seconds residence time.[5] If a thermal incinerator is properly designed and operated to produce the optimum conditions in the combustion chamber, it should be capable of higher than 99 percent destruction efficiencies for nonhalogenated VOC, when the VOC concentration in the gas stream is above approximately 2,000 ppmv.[6]

5.5.3.2 Control Efficiency for Particulate Matter

Controlled emissions and/or efficiency test data for PM in incinerators are not generally available in the literature. Emission factors for PM in phthalic anhydride processes with incinerators were available, however.[10] The PM control efficiencies for these processes were calculated from the reported emission factors and are shown in Table 5.5-1. The PM control efficiencies ranged from 79 to 96 percent control for total PM.

In EPA's 1990 National Inventory,[7] incinerators were used as control devices for PM to achieve from 25 to 99.9 percent control of PM_{10} at point source facilities. The VOC control reported for these devices ranged from 0 to 99.9 percent. These ranges of control efficiencies are large because they include facilities that do not have VOC emissions and control only PM (these facilities would report 0 percent efficiency for VOC control), as well as facilities which have low PM emissions and are primarily concerned with controlling VOC.

5.5.4 Applicability

Although incinerators can be used to any organic material, their application is limited to a range of gas vapor concentration. To prevent explosions, the vapor concentration must be substantially below the gas lower flammable level (lower explosive limit [LEL]). As a rule, a factor of 4 is employed to give a margin of for safety.[2] Therefore, incinerators are not likely to be used for processes with very high VOC content. The presence of halogens also requires additional equipment such as scrubbers for acid gas removal.[4]

Thermal incinerators can be designed to handle minor fluctuations in flow rate. However, processes with the potential for excessive fluctuations in flow rate (i.e., process upsets) may not be suitable for incinerator use, since control efficiency could decrease outside the acceptable range.[4] Flares may be an appropriate control for processes with excessive fluctuation potential. Table 5.5-2 presents the operating conditions required for satisfactory incinerator performance in various industrial applications.[3] Note that the residence time and incinerator temperature required for PM control is much higher than for non-PM sources.

An examination of the EPA's 1990 National Inventory,[7] presented in showed that the primary source categories in which incinerators were used for PM control were:

Table 5.5-1 PM Control Efficiencies for Thermal Incinerators in Phthalic Anhydride Manufacturing Processes (Reference 10)

Process Unit	PM Emission Factor (lb PM/ton product)		Calculated Control Efficiency (percent)
	Uncontrolled	Controlled	
O-xylene Processing			
Oxidation	138	7	95
Pretreatment	13	0.7	95
Distillation	89	4	96
Naphthalene Processing			
Oxidation	56	11	80
Pretreatment	5	1	80
Distillation	38	8	79

- Petroleum and Coal Production
- Chemical and Allied Product Manufacturing
- Primary Metal Industries
- Electronic and Other Electric Equipment.

These source categories were identified from the reported data in the 1990 National Inventory,[7] and correspond to facilities that reported PM_{10} control efficiencies for incinerators likely to have been used as primary control devices.

5.5.5 Costs of Incinerators

The costs of installing and operating an incinerator include both capital and annual costs. Capital costs are all of the initial equipment-related costs of the incinerator. Annual costs are the direct costs of operating and maintaining the incinerator for one year, plus such indirect costs as overhead; capital recovery; and taxes, insurance, and administrative charges. The following sections discuss capital and annual costs for incinerators, referenced to the fourth quarter of 1996, unless otherwise noted.

Incinerators designed for PM control are likely to have higher costs than incinerators designed for VOC control, because of the higher temperatures and longer gas residence times are needed for PM destruction (see Table 5.5-2). Incinerators designed for PM control are also likely to need more supplemental fuel to maintain the higher temperatures and larger combustion chambers to achieve the longer residence times. Since the incinerator cost data presented below were probably derived for incinerators designed for VOC control only, the actual costs for incinerators designed for PM control are likely to be higher.

Table 5.5-2 Operational Requirements for Satisfactory Incinerator Performance for Various Industrial Applications and Control Levels (Reference 3)

Application	Control Level (percent)	Residence Time (sec)	Temperature (°F)
HC Control	>90	0.3-0.5	1100-1250[a]
HC + CO	>90	0.3-0.5	1250-1500
Odor			
Low control	50-90	0.3-0.5	1000-1200
Medium control	90-99	0.3-0.5	1100-1300
High control	>99	0.3-0.5	1200-1500
Smokes/Plumes			
White smoke (liquid mist)	>99	0.3-0.5	800-1000[b]
HC and CO	>90	0.3-0.5	1250-1500
Black smoke (soot and other combustible PM)	>99	0.7-1.0	1400-2000

[a] Temperatures of 1400 to 1500°F may be required if there is a significant amount of any of the following: methane, cellosolve, and substituted aromatics (e.g., toluene and xylenes).

[b] Operation for plume abatement only is not recommended, since this merely converts a visible hydrocarbon emission into an invisible one and frequently creates a new odor problem because of partial oxidation in the incinerator.

The use of a catalytic incinerator for PM control is limited because catalysts are subject to poisoning/blinding from PM;[2] consequently, only thermal incinerator costs are discussed in this section. For information on the costs of catalytic incinerators, consult *Estimating Costs of Air Pollution Control*[11] and EPA's *"CO$T-AIR" Control Cost Spreadsheets.*[12]

5.5.5.1 Capital Costs

The total capital investment (TCI) for incinerators includes all of the initial capital costs, both direct and indirect. Direct capital costs are the purchased equipment costs (PEC), and the costs of installation (foundations, electrical, piping, etc.). Indirect costs are related to the installation and include engineering, construction, contractors, start-up, testing, and contingencies. The PEC is calculated based on the incinerator specifications. The direct and indirect installation costs are calculated as factors of the PEC.[11] The equipment cost presented in Table 5.5-3 are the TCI cost factors for custom incinerators (as opposed to packaged units).

The flue gas flow rate and auxiliary fuel requirement are the most important sizing parameters for a thermal incinerator. The former determines the equipment size and cost, while the latter comprises most of annual operating and maintenance costs. These parameters are interdependent, based on material and energy balances taken around the incinerator.[9]

Figure 5.5-5 shows total capital investment vs. flow rate (size) for a thermal incinerator with recuperative heat recovery equipment.[12] Three levels of heat recovery are shown in Figure 5.5-5: 0 percent, 35 percent, and 50 percent. For the purposes of the figure, the thermal incinerator was assumed to operate at a combustion temperature of 1600°F and the waste gas was assumed to have a heat content of 4 Btu/SCF. The curves illustrate two phenomena: 1) the direct proportionality of capital cost to flow rate (size), and 2) the proportionality of capital cost to heat recovery efficiency. That is, capital costs increase with both increasing flow rate (size) and increasing heat recovery efficiency.

Figure 5.5-6 shows total capital investment vs. flow rate (size) for thermal incinerators with 85 percent and 95 percent regenerative heat recovery systems.[12] As in the previous figure, the thermal incinerator was assumed to operate at a combustion temperature of 1700°F and the waste gas was assumed to have a heat content of 4 Btu/SCF. Also, as in the previous figure, capital costs for incinerators with regenerative heat recovery systems increase with increasing flow rate (size) and decrease with increasing heat recovery efficiency.

A comparison between the capital cost of incinerators with recuperative vs. regenerative heat recovery systems shows that for the same size incinerator, the capital investment of a regenerative heat recovery system is over twice the capital investment required for an incinerator with a recuperative heat recovery system.

5.5.5.2 Annual Costs

The total annual cost of an incinerator consists of both direct and indirect costs. Direct annual costs are those associated with the operation and maintenance of the incinerator. These include labor (operating, supervisory, coordinating, and maintenance); maintenance materials; operating materials; electricity; and supplemental fuel, if applicable.

Table 5.5-3 Capital Cost Factors for Thermal Incinerators (from Reference 11)

Cost Item	Factor
Direct Costs	
Purchased equipment costs	
Incinerator + auxiliary equipment	As estimated (A)
Instrumentation	0.10 A
Sales taxes	0.03 A
Freight	0.05 A
Total Purchased Equipment Cost (PEC)	B = 1.18 A
Direct installation costs	
Foundations and supports	0.08 B
Handling and erection	0.14 B
Electrical	0.04 B
Piping	0.02 B
Insulation for ductwork	0.01 B
Painting	0.01 B
Total direct installation cost	0.30 B
Site Preparation and Buildings	As required (Site)
Total Direct Cost, DC	1.30 B + Site
Indirect Costs (installation)	
Engineering	0.10 B
Construction and field expense	0.05 B
Contractor fees	0.10 B
Start-up	0.02 B
Performance test	0.01 B
Contingencies	0.03 B
Total Indirect Cost (IC)	0.31 B
Total Capital Investment = DC + IC	1.61 B + Site

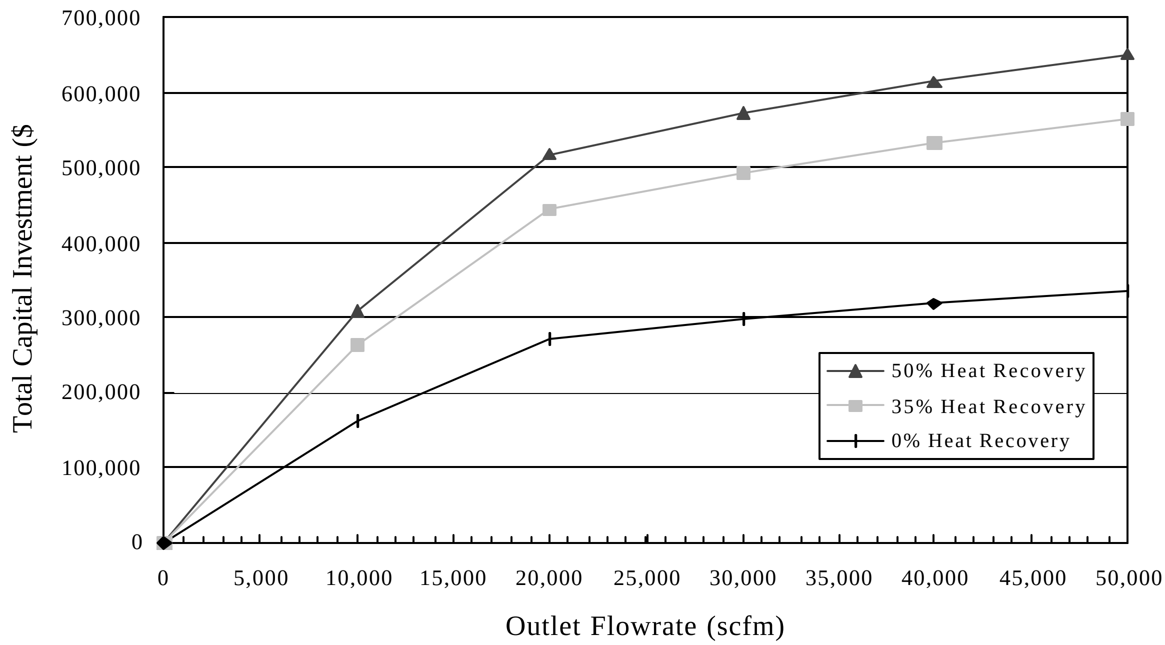

Figure 5.5-5. Total Capital Investment vs. Flow Rate for a Thermal Incinerator with 0, 35, and 50 Percent Recuperative Heat Recovery (Reference 12).

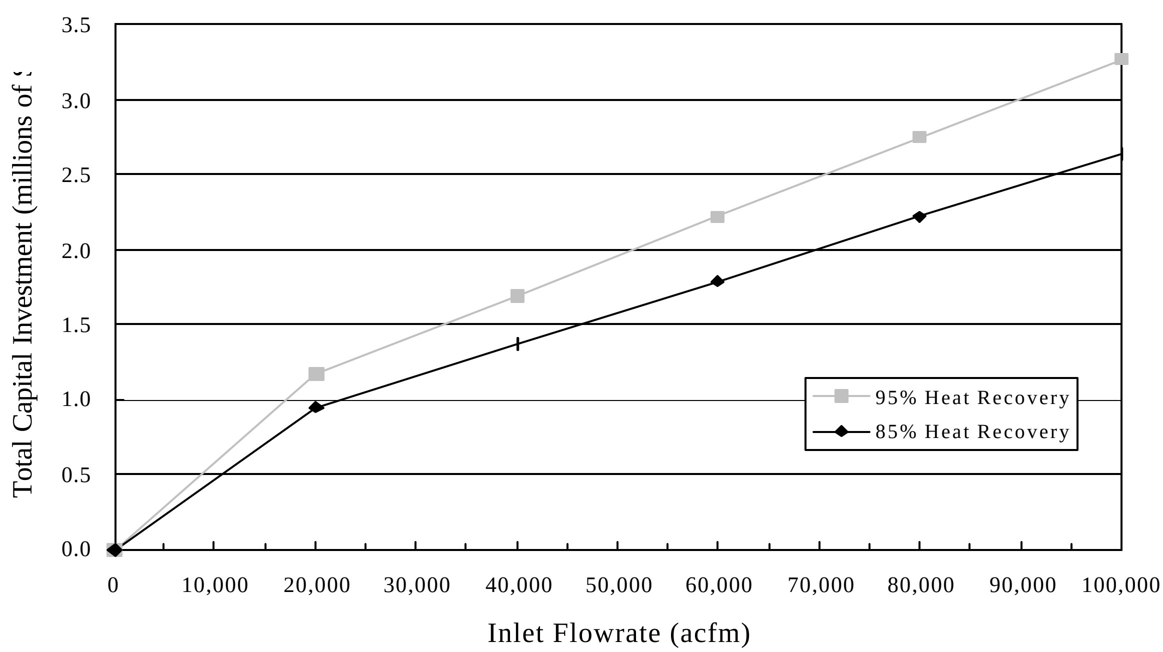

Figure 5.5-6. Total Capital Investment vs. Flow Rate for a Regenerative Thermal Oxidizer with 85 and 95 Percent Heat Recovery (Reference 12).

Indirect annual costs include taxes, insurance, administrative costs, overhead, and capital recovery. All of these costs except overhead are dependent on the TCI. Table 5.5-4 lists the annual cost parameters that impact incinerator costs, with typical values provided for each parameter. Table 5.5-5 provides the annual cost factors for incinerators. It is difficult to generalize these costs for all incinerators, since annual costs are very site-specific.[11]

The supplemental fuel and electricity requirements for an incinerator are likely to have a large impact on incinerator annual costs. The requirements for each can be estimated from incinerator design values. The auxiliary heat requirement to be supplied by the fuel, usually natural gas, can be calculated using the incinerator design equations described below.

An incinerator is designed to handle a total volumetric gas flow rate (Q_f) equal to the waste gas inlet flow rate (Q_i), which is known, and auxiliary fuel gas flow rate (Q_a):

$$Q_f = Q_i + Q_a \qquad \text{(Eq. 5.5-4)}$$

and where the requirements for auxiliary fuel gas are determined with the following equation:

$$Q_a = (x/y)(Q_i) \qquad \text{(Eq. 5.5-5)}$$

for

$$x = (1.1\ C_{pf}\,(T_f - T_r)) - (C_{pi}\,(T_i - T_r)) - h_1 \qquad \text{(Eq. 5.5-6)}$$

$$y = h_a - 1.1C_{pf}\,(T_f - T_r) \qquad \text{(Eq. 5.5-7)}$$

where Q_f is the flue gas flow rate (SCFM), Q_i is the inlet waste gas flow rate (SCFM),Q^a is the auxiliary fuel gas (heat) requirement (SCFM), C_{pf} is the mean heat capacity of gas leaving the combustion chamber (Btu/SCF-°F), C_{pi} is the mean heat capacity of gas entering the combustion chamber (Btu/SCF-°F), T_f is the combustion chamber temperature (°F), T_i is the waste gas inlet temperatures (°F), T_r is the reference temperature, equal to the inlet fuel temperature (typically 70°F), h_1 is the waste gas heat content (Btu/SCF), and h_a is the fuel heating value (Btu/SCF).

Electricity to run the incinerator exhaust fan is calculated with the following equation:

$$\text{Fan Power (kW)} = (1.575\text{x}10^{-4})\ )P\ Q\ /\ n \qquad \text{(Eq. 5.5-8)}$$

where)P is the system pressure drop (inches of water), Q is the waste gas volumetric flow rate through system (ACFM), and n is the efficiency of fan and motor (generally 0.50-0.70).

Figure 5.5-7 shows annual operating cost curves for an example thermal incinerator with recuperative heat recovery systems at three levels of heat recovery efficiency: 0, 35, and 50 percent, and 85 percent regenerative heat recovery. For these curves, the example incinerator was assumed to operate 8,000 hours per year, at a combustion temperature of 1700°F, with a waste gas heat content of 4 Btu/SCF. Figure 5.5-7 shows that annual operating costs for incinerators with recuperative heat recovery decrease with increasing heat recovery system efficiency, and increase with increasing inlet flow rates (size).

Table 5.5-4. Incinerator Annual Cost Parameters (from Reference 11)

Parameter	Description	Typical Values
Direct Cost Parameters		
Operating factor (OF)	Yearly incinerator (INC) operation hours	8,000
Operator labor rate (OR)	Cost of operator labor	\$12.50/hr[a]
Maintenance Labor Rate (ML)	Cost of maintenance labor	1.1 (OR)[a]
Operator shift factor (OS)	Fraction of operator's shift spent on INC	0.5
Maintenance shift factor (MS)	Fraction of maintenance shift spent on INC	0.5
Electricity rate (ER)	Cost of electricity	\$0.07/kW-hr[a]
Fuel (F)	Cost of fuel (natural gas)	\$2.30/10^3 SCF[a]
Indirect Costs		
Annual Interest Rate (I)	Opportunity cost of the capital	7 percent[c]
Operating Life (n)	Expected operating life of INC	10 years[c]?
Capital Recovery Factor (CRF)	Function of (n) and (I)	0.0944[d]
Taxes (TAX)	Fraction of TCI[d]	0.01[c]
Insurance (INS)	Fraction of TCI[d]	0.01[c]
Administrative Costs (AC)	Fraction of TCI[d]	0.02[c]

[a] Estimated for 1996 from currently available information.

[b] Estimates from "CO\$T-AIR" Control Cost Spreadsheets (Reference 12).

[c] Capital recovery factor is calculated from the following formula:

$$CRF = \{I(1+I)^n\} \div \{(1+I)^n - 1\},$$

where I = interest rate (fraction) and n = operating life (years).

[d] The total capital investment (TCI) can be escalated to current values by using the Vatavuk Air Pollution Control Cost Indicies (VAPCCI), described in Section 5.4.5.

Table 5.5-5. Annual Cost Factors for Incinerators (Reference 12).

Cost Item	Formula[a]	Factor
Direct Costs		
Labor		
Operator (OL)	(OF)×(OR)×(OS)	A
Supervisor (SL)	(SF)×(OL)	0.15 A
Maintenance (ML)	(OF)×(MR)×(MS)	1.1 A
Maintenance materials (MM)	(MF)×(ML)	1.1 A
Electricity (E)	Power[b] × (ER)	E
Fuel (F)	Fuel[c] X (FR)	F
Total Direct Cost (DC)		3.35 A + E + F
Indirect Costs		
Overhead	(OV)×(OL+SL+ML+MM)	2.01 A
Capital Recovery	(CRF)×(TCI)	0.1424 TCI
Taxes	(TAX)×(TCI)	0.01 TCI
Insurance	(INS)×(TCI)	0.01 TCI
Administrative Costs	(AC)×(TCI)	0.02 TCI
Total Indirect Cost (IC)		2.01 A + 0.1824 TCI
Total Annual Cost (DC + IC)		5.36 A + 0.1824 TCI + E + F

[a] Includes values also described in Table 5.5-5.
[b] Equal to the total power requirements, i.e. electricity and fan.
[c] Equal to the auxiliary fuel requirements.

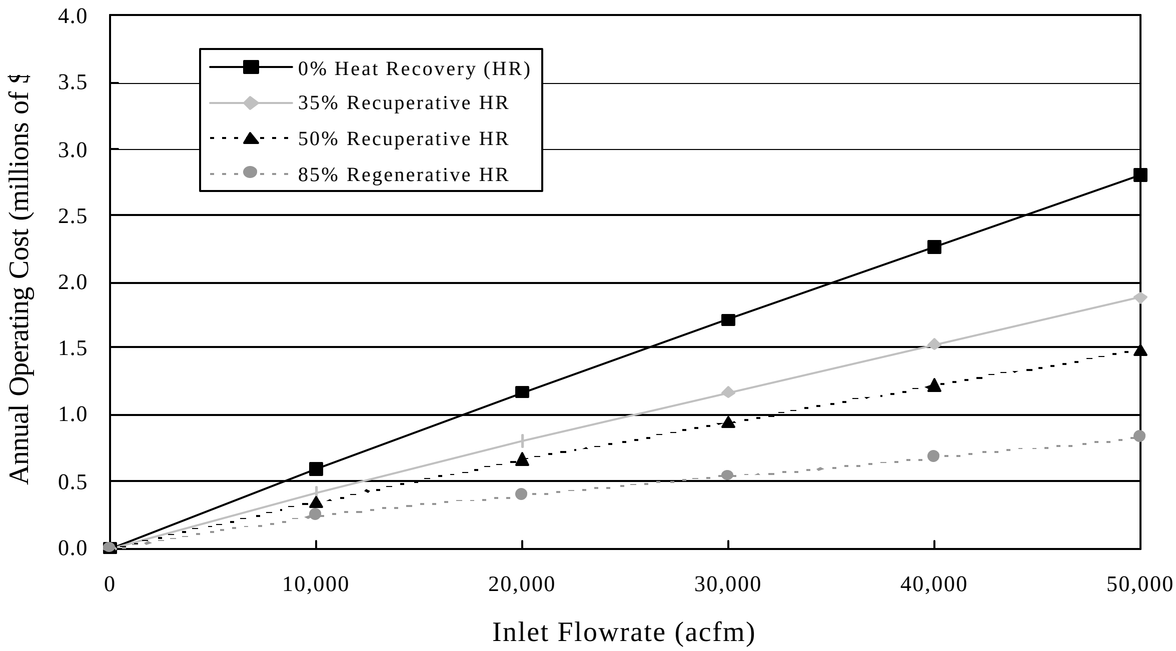

Figure 5.5-7. Annual Costs for Incinerators with Recuperative and Regenerative Heat Recovery (Reference 12).

Figure 5.5-7 also shows that annual costs for the example incinerator with regenerative heat recovery increase with inlet flow rate. Regenerative thermal incinerators achieve higher heat recovery ($85 percent vs. #50 percent) at lower annual costs than recuperative systems. However, the higher capital costs of regenerative systems (see Figure 5.5-6) compared trecuperative systems (see Figure 5.5-5), present a trade-off in the choice incinerator type.

5.5.6 Energy and Other Secondary Environmental Impacts

No liquid, solid or hazardous wastes are generated from the use of thermal incinerators. As discussed above, the energy impacts of incinerator operation include that associated with the energy required to run the fan and are proportional to the gas flow rate and the system pressure drop.

Nitrogen oxides are also generated as air pollution during incineration. Because of the lower operating temperatures of catalytic incinerators, less NO_x is generated with this type of incinerator. Based on the combustion of natural gas only, thermal incinerators have the potential to generate 100 pounds (lb) of NO_x per 10^6 SCF of natural gas combusted, and catalytic incinerators have the potential to generate 50 lb of NO_x per 10^6 SCF of natural gas.[13]

5.5.7 References for Section 5.5

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